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Matthew J. Helmers
Iowa State University, mhelmers@iastate.edu

Xiaobo Zhou
Iowa State University

Heidi Asbjornsen
University of New Hampshire, hasbjorn@iastate.edu

Randy Kolka
U.S. Department of Agriculture

Mark D. Tomer
U.S. Department of Agriculture

Water quality benefits of perennial filter strips in row-cropped watersheds

Matthew J. Helmers, associate professor, Agricultural and Biosystems Engineering, Iowa State University; Xiaobo Zhou, assistant scientist, Agricultural and Biosystems Engineering, Iowa State University; Heidi Asbjornsen, associate professor, Natural Resource and the Environment, University of New Hampshire; Randy Kolka, soil scientist, USDA Forest Service, Northern Research Station; Mark D. Tomer, soil scientist, USDA Agricultural Research Service, National Laboratory for Agriculture and the Environment

Introduction

Nonpoint source pollution is an increasingly serious problem in agricultural landscapes, especially as growing populations intensify pressures on a fixed land area for food and energy, and climate change threatens production stability. Vegetative filter strips (VFS) have been demonstrated as a practical strategy in reducing soil loss and nutrient transport from agricultural land. While restoration of native grassland on agricultural landscapes would improve environment quality, however, this practice is not feasible across large regions where local communities depend on agriculture. One alternative strategy for erosion control and water quality improvement is the incorporation of relatively small amounts of vegetative filter strips in strategic locations within agricultural landscapes (Dosskey et al., 2002). Vegetative filter strips within crop production systems are bands of perennial vegetation established at the lower portion of the watershed or distributed upslope along the contour (Dillaha et al., 1989). They are designed to remove sediment and other pollutants from agricultural runoff by slowing flow velocity, increasing water infiltration, and promoting plant uptake of excess nutrients.

The majority of studies assessing the environmental benefits of VFS were conducted on a plot scale, and assessments at the watershed scale are lacking (Helmers et al., 2005; Baker et al., 2006). Accounting for the heterogeneity of watersheds in topography, soils and land use is particularly challenging. This is underscored by findings suggesting that performance of VFS under on-farm conditions is rarely as effective as that for plot settings (Blanco-Canqui et al., 2006). This trend is largely explained by the less uniform and more concentrated flow that develops in watersheds having longer slopes compared to shorter slopes at the plot scale. Further, the effectiveness of VFS has often been investigated from simulated or natural rainfall events over relatively short periods. Therefore, there is a critical need for long-term monitoring and multi-year data to assess the performance of VFS with commonly-adopted field operations, while accounting for variability in both climate and field conditions.

This paper presents results from the first four years of a long-term field experiment testing the impacts of prairie filter strips (PFS) on sediment and nutrient export in runoff from watersheds maintained under annual rowcrop systems in central Iowa.

Materials and methods

The study was conducted at the Neal Smith National Wildlife Refuge (NSNWR; 41°33′ N; 93°16′ W) in Jasper County, Iowa. A total of 12 watersheds in the NSNWR and within the Walnut Creek watershed were selected to evaluate the benefits of integrating PFS in rowcrop agriculture for enhancing water quality in central Iowa (Figure 1). A balanced incomplete block design was implemented across four blocks each with three plots, with each treatment excluded once from of the blocks. Two blocks are located at Basswood, one block at Interim, and one block at Orbweaver. The size of the watersheds varied from 1.2 to 7.9 acres, with average slopes ranging from 6.1 to 10.5% (Table 1). Ladoga silt loam (fine, smectitic, mesic Mollic Hapludalf) and Otley silty clay loam (fine, smectitic, mesic Oxyaquic Argiudolls) are predominant soils in the study watersheds.

Table 1. Site description and experimental design.

	Size (acre)	Slope (%)	Location and percent of grass filters*
Basswood-1	1.3	7.5	10% at footslope
Basswood-2	1.2	6.6	5% at footslope and 5% at upslope
Basswood-3	1.2	6.4	10% at footslope and 10% upslope
Basswood-4	1.4	8.2	10% at footslope and 10% upslope
Basswood-5	3.1	8.9	5% at footslope and 5% upslope
Basswood-6	2.1	10.5	All rowcrops
Interim-1	7.4	7.7	3.3% at footslope, 3.3% at sideslope, and 3.3% at upslope
Interim-2	7.9	6.1	10% at footslope
Interim-3	1.8	9.3	All rowcrops
Orbweaver-1	2.9	10.3	10% at footslope
Orbweaver-2	5.9	6.7	6.7% at footslope, 6.7% at sideslope, and 6.7% at upslope
Orbweaver-3	3.1	6.6	All rowcrops

*Percent of grass filters = area of filters / area of watershed

Prior to treatment, all watersheds were in bromegrass for at least 10 years without fertilizer application. In August 2006, all watersheds were uniformly tilled with a mulch tiller. Basswood-1-6 and Orbweaver-1 were tilled again in spring 2007 to further level field residue. Starting in spring 2007, a two-year no-till corn-soybean rotation (soybeans in 2007) was implemented along the contour in areas receiving the rowcrop treatment. Standard herbicide- and fertilizer-based weed and nutrient management practices were applied in each watershed. Consistent with methods used for other prairie reconstructions at the NSNWR, areas receiving PFS treatment were seeded with a diverse mixture of native prairie forbs and grasses using a broadcast seeder on July 7, 2007. No fertilizer was applied in the PFS areas.

Each watershed received one of 4 treatments (3 replicates per treatment): 100% rowcrop (RC), 10% PFS at the footslope position, 10% PFS distributed between the footslope position and in contour strips further upslope in the watershed, and 20% PFS distributed between the footslope position and in contour strips further upslope in the watershed (Zhou et al., 2010). Treatments were randomly assigned to watersheds within each block.

A fiber glass H flume was installed at the bottom of each watershed in 2005 and early 2006 according to the Field Manual for Research in Agricultural Hydrology. Plywood wing walls were constructed at the bottom of watershed to guide surface runoff to the flumes. ISCO 6712 automated water samplers (ISCO, Inc., Lincoln, NE) equipped with pressure transducers were installed in 2007 at each flume to record flow rate and collect water samples. Flow stage was measured by pressure transducers and logged every 5 minutes. Each ISCO autosampler contained 24 one-liter bottlers that were filled during storm events. A total of three samples were placed in each bottle in sequential fashion. Water samples were refrigerated at 4°C until analysis. The data (including flow stage and a record of sample date and time) were downloaded on at least a monthly interval using an ISCO 581 Rapid Transfer Device (RTD).

Concentrations of total suspended solids (TSS), total nitrogen (N) and total phosphorus (P) in surface runoff were analyzed in the Agricultural & Biosystems Engineering Water Quality Research Laboratory at Iowa State University. Sediment and nutrient load was then calculated based on the measured concentrations and total flow volume for the specific period during which the sample was collected. Flow-weighted concentrations were calculated by dividing the total load by the total flow volume for the period.

Meteorological data were obtained from two weather stations located within the NSNWR and near the study watersheds: the Mesonet station is 0.8 – 2.3 miles from the watersheds and the NOAA station is 0.7 – 2.1 miles from the watersheds. The observed rainfall amount from the two weather stations was averaged to obtain daily rainfall during 2007-2010 to account for spatial variability in rainfall distribution.

Statistical analysis of the data was performed using the General Linear Model (GLM) procedures for SAS (SAS Institute, 2003).

Results and discussion

The entire study period (2007 – 2010) received higher than normal rainfall compared to the long-term average. Total rainfall during the growing season (April – October) ranged from 31.9 inches in 2009 to 48.1 inches in 2010 (Table 2), well above the long-term mean of 28.1 inches. Year 2008 had a wet June and July but a dry August. Monthly rainfall was 13.3 and 14.7 inches for June and August 2010, respectively; the total rainfall amount in these two months alone was already greater than the long-term mean rainfall for the entire growing season. The largest rainfall event during the monitoring period occurred on August 8 – 11, 2010, with 9.8 inches of rain producing 8.2 inches of discharge, which was approximately 60% of the total flow during 2007 – 2009. This event produced record flood stages in several nearby streams and rivers. The driest month was October 2010, with only 0.5 inches of rainfall compared to the 2.6 inches on average for October.

Table 2. Monthly precipitation during April through October in 2007-2010 at the Neal Smith National Wildlife Refuge, IA.

	2007	2008	2009	2010
	-------------------------- inch ------------------------			
April	4.9	4.5	4.9	4.9
May	5.8	4.8	3.0	4.6
June	3.4	10.5	5.8	13.3
July	1.8	8.1	3.3	6.1
August	8.4	2.2	6.2	14.7
September	3.7	4.7	2.2	4.0
October	5.0	3.2	6.5	0.5
Total	**33.0**	**38.0**	**31.9**	**48.1**

Surface runoff exhibited a wide range of inter-annual variation, varying from only 1.3 inches in 2007 to 14.1 inches in 2010. Overall, increasing rainfall led to greater runoff with the exception of 2007, which had slightly more rainfall but much less runoff than 2009. This could, in part, be attributed to differences in seasonal rainfall distribution between the two years: more rainfall occurred during August and September in 2007 than in 2009, and the late-season rainfall events in 2007 may have resulted in less runoff due to greater interception by the well-developed crop canopy and high evapotranspiration (ET) during this growth stage. As expected, more runoff was observed in spring than in summer for a comparable rainfall amount due to wet field conditions and low water use by crops at their early growth stage. In 2009, as an example, 4.9 inches rainfall in April produced 2.4 inches runoff, while 6.2 inches rainfall in August only produced 0.02 inches runoff.

PFS treatments reduced surface runoff to varying extents compared to 100% row-cropped fields. The higher runoff amount in 2007 for some watersheds with PFS compared to 100% agricultural watersheds could be due to the limited vegetation cover in the PFS at that time. Averaged over the four years, runoff was reduced by 59, 17, and 24% for treatments of 10% PFS at footslope, 10% PFS in contour strips, and 20% PFS in contour strips, respectively, compared with 100% rowcrop. Overall, the reduction was more evident at the early growth stage of rowcrop (Figure 1), likely due in part to the higher ET and canopy interception in PFS than cropland during this period. In contrast, watersheds with 100% cropland had less runoff than watersheds with PFS during rainfall events occurring when crops were completely developed. However, other factors including improved soil structure and infiltration may also account for the difference in runoff amount between treatments. During consecutive days of rainfall (9.8 inches) in August 8-11, 2010, watersheds with PFS had 25% less runoff than watersheds with 100% rowcropped corn. Since corn had comparable ET with native prairie at this growth stage, more runoff water likely infiltrated into subsurface soils under PFS. The improved soil structure and dampened flow rates under PFS could facilitate infiltration of runoff water.

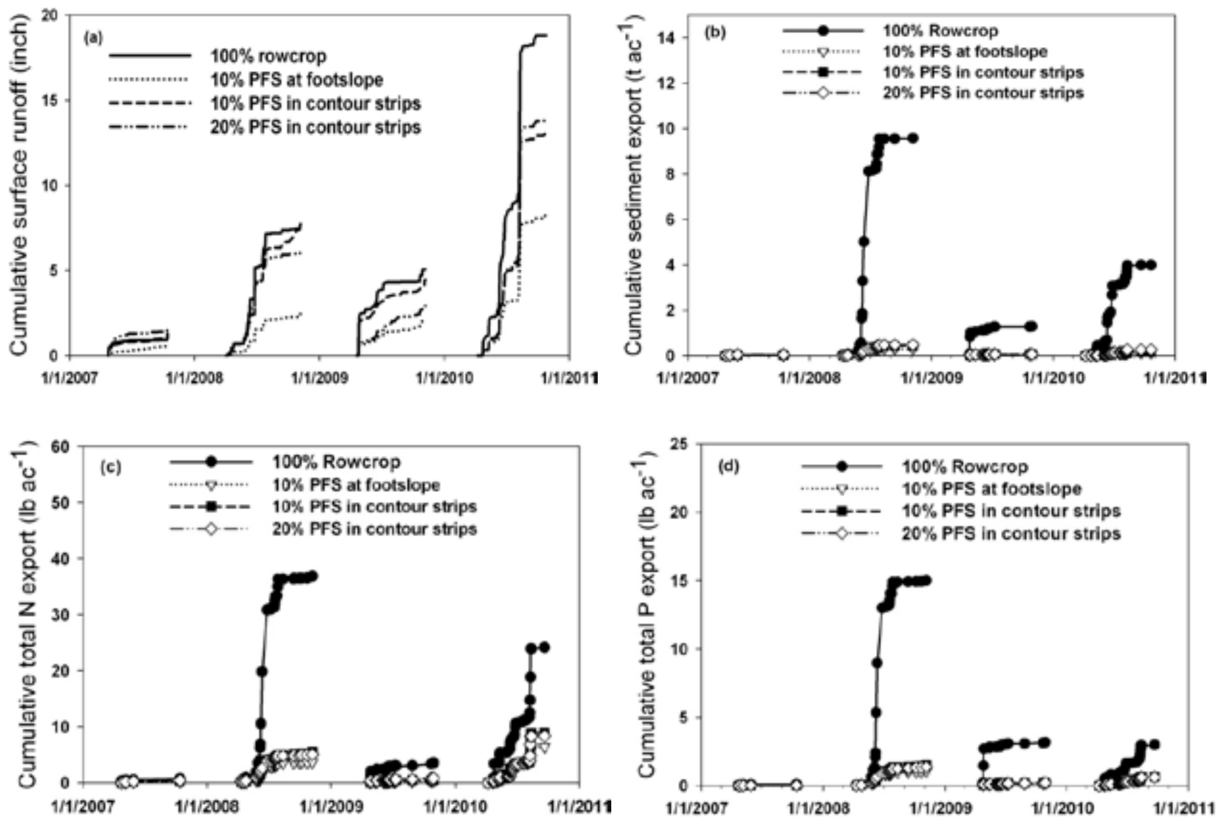

Figure 1. Cumulative annual (a) surface runoff, (b) sediment export, (c) total N export, and (d) total P export in runoff from cropped watersheds during 2007-2010.

It is important to note that no-tillage alone did not prevent soil loss on these 6-10% slopes from approaching or even exceeding the annual tolerable soil loss rate of 5 t ac-1 during wet years of 2008 and 2010; however, the combination of no-tillage and PFS was highly effective and kept average sediment export to below 0.5 t ac-1 during the crop season (April through October) of the entire study period. Watersheds with 100% rowcrop had significantly higher sediment concentration in runoff and total sediment yield than watersheds with PFS (Table 3 and Figure 1). For example, the annual sediment concentration was reduced from 12,016 ppm in 100% cropped watersheds to 687-818 ppm in PFS watersheds in 2008. Similarly, the total measured total N and total P export during the growing season were greatly reduced in the watersheds with PFS compared to the watersheds without PFS (Table 3 and Figure 1).

Sediment and nutrient export from the watersheds were highly variable during the study period. Higher sediment and nutrient export occurred in 2008 and 2010 than in 2007 and 2009 due to the relatively higher precipitation in 2008 and 2010. Year 2008 had the highest sediment and nutrient load, although 2010 had 48 inches of precipitation during the growing season compared to 38 inches in 2008. This could be attributed to the initial soil disturbance by the tillage that occurred in 2006 and 2007.

Table 3. Annual flow-weighted sediment, TN and TP concentrations in surface runoff during growing season (April-October). Letters indicate the significance test of mean difference among four treatments within each year at $p<0.1$.

	100%RC	10%PFS at footslope	10%PFS in contour strips	20%PFS in contour strips	Mean
			Sediment (ppm)		
2007	125.4b	77.8b	90.6b	263.0a	139.2
2008	12016.3a	818.3b	790.6b	686.7b	3578.0
2009	1963.8a	129.3b	74.7b	183.1b	634.4
2010	1419.4a	176.3b	90.5b	138.9b	481.7
Average	**4222.68a**	**335.12b**	**297.38b**	**322.90b**	
			TN (ppm)		
2007	3.4a	5.2a	4.0a	4.2a	4.2
2008	61.3a	9.5b	8.0b	4.7b	20.9
2009	15.6a	3.8a	5.1a	2.2a	6.7
2010	11.5a	5.6b	6.4b	6.1b	7.4
Average	**22.9a**	**6.0b**	**5.8b**	**4.3b**	
			TP (ppm)		
2007	1.0a	0.5a	0.4a	0.3a	0.5
2008	13.9a	1.6b	1.5b	1.4b	4.9
2009	6.2a	0.9a	0.7a	0.8a	1.8
2010	1.6a	0.8b	0.5b	0.4b	0.8
Average	**5.2a**	**1.1ab**	**0.9b**	**0.6b**	

Summary

Sediment and nutrient export from 12 agricultural watersheds in central Iowa was monitored at watershed outlets from 2007-2010 to evaluate the effectiveness of prairie filter strips (PFS) in improving water quality from agricultural runoff. The above normal annual precipitation and number of extreme events during the study period provided the opportunity to evaluate the effectiveness of PFS in reducing pollutant transport. The four-year study suggests that an appropriate placing of PFS at the watershed scale could effectively reduce sediment and nutrient loss and supports what has been found previously at the plot scale. The amount and distribution of PFS showed no significant impact on runoff and pollutant load likely due to the relatively large width of the PFS in this study, suggesting that converting 10% of agricultural cropping systems to perennial systems at the bottom of a watershed could effectively control erosion and nutrient loss from cropped area at the small watershed scale while being convenient for field operations. For areas with severe soil erosion problems additional conservation measures, including but not limited to terraces, riparian buffers, and change in land use should be considered.

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References

Baker, J.L., Helmers, M.J., Laflen, J.M., 2006. Water management practices: rain-fed cropland, in: Schnepf, M., Craig, C. (Eds.), Environmental benefits of conservation on cropland: the status of our knowledge. Soil and Water Conservation Society, Ankeny, Iowa, pp. 89-130.

Blanco-Canqui, H., Gantzer, C.J., Anderson, S.H., 2006. Performance of grass barriers and filter strips under interrill and concentrated flow. J. Environ. Qual. 35, 1969-1974.

Dillaha, T.A., Reneau, R.B., Mostaghimi, S., Lee, D., 1989. Vegetative filter strips for agricultural nonpoint source pollution-control. Trans. ASAE 32, 513-519.

Dosskey, M.G., Helmers, M.J. Eisenhauer, D.E., Franti, T.G., Hoagland, K.D., 2002. Assessment of concentrated flow through riparian buffers. J. Soil Water Conserv. 57, 336-343.

Helmers, M.J., Eisenhauer, D., Dosskey, M.G., Franti, T.G., Brothers, J.M., McCullough, M.C., 2005. Flow pathways and sediment trapping in a field-scale vegetative filter. Trans. ASAE 48, 955-968.

SAS Institute, 2003. The SAS system for Windows. Release 9.1. SAS Institute, Cary, NC.

Zhou, X., Helmers, M.J., Asbjornsen, Kolka, H. R., Tomer., M.D., 2010. Perennial filter strips reduce nitrate levels in soil and shallow groundwater after grassland-to-cropland conversion. J. Environ. Qual. 39, 2006-2015.